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REPORT

of the

1992 DEFENSE SCIENCE BOARD
TASK FORCE

on

MICROELECTRONICS
RESEARCH FACILITIES

JUNE, 1992

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Office of the Under Secretary of Defense for Acquisition
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DEFENSE SCIENCE
BOARD

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

June 30, 1992

MEMORANDUM FOR DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Report of the Defense Science Board (DSB) Task Force on
Microelectronics Research Facilities

I am pleased to forward the final report of the DSB Task Force on Microelectronics Research Facilities, which was chaired by Dr. William G. Howard, Jr. The report responds to the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories recommendation that "an independently appointed review group should assess the advantages and disadvantages of a single microelectronics research facility for all three services".

In developing their recommendations, the Task Force reviewed the missions and uniqueness of the multiple service research facilities and the adequacy of these facilities to support weapon system acquisition. In addition, they examined the required capital investment costs to maintain the necessary state-of-the-art facilities, as well as the related industrial sector and GOCO activities.

The Task Force determined that microelectronics is a pervasive, enabling technology and that DoD needs a strong microelectronics program in all phases from research through system development and support. Such a program, however, does not require the myriad of costly fabrication facilities present now; rather, a single DoD Tri-Service corporate microelectronics facility should be capable of developing defense unique technologies and alleviate the deficiencies in industry and academia. Also, since there exists a spectrum of microelectronics research which is service unique and system specific, each military department should have a single applications-oriented microelectronics facility selected from an existing MRF and closely associated with the development and user communities. Finally, because management, coordination and communication is necessary to ensure efficiency, effectiveness, and quality, the Task Force recommends that the present Reliance program be expanded in scope to cover facilities and equipment, and its mechanism used to provide guidance to the corporate facility microelectronics activities.

I fully concur with the recommendations of the Task Force, recommend that you review the members Letter of Transmittal, the Executive Summary, and the implementation section and forward the report to the Undersecretary for Acquisition and the Secretary of Defense.

John S. Foster, Jr.

John S. Foster, Jr.
Chairman

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DEFENSE SCIENCE
BOARD

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

June 15, 1992

SUBJECT: Report of the Defense Science Board (DSB) Study on Microelectronics Research Facilities (MRF)

Attached is the final report of the 1992 Defense Science Board study on MRF's. The study was a follow-on to the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories and was specifically formed to assess the advantages and disadvantages of a single MRF for the Department of Defense.

In providing this assessment, the Task Force investigated a wide range of relevant issues to include:

- the mission of service MRF's and their uniqueness to each service
- the ability of the MRF's to support weapon systems acquisition, i.e., the ease of cost effective technology transfer to systems
- the capital investment required to maintain state of the art MRF's

The basic findings conclude that electronic material and devices technology which drives microelectronic research is a critical and pervasive science area, and that effective management of this research is vitally important to the successful evolution of the technology from research through system integration. It is also apparent that each of the services has existing capabilities to support their users across the spectrum of microelectronics applications; however, the rapid rate of change of microelectronics technology is escalating the cost of the necessary tools and facilities to an unreasonable level.

The essence of our recommendations proposes a Tri-Service microelectronics laboratory system comprised of four MRF's, one for each service focussed primarily on applications of microelectronics technology and one corporate MRF focussed more on long range research in support of needs generic to all three services. NRL is suggested as the corporate Tri-Service laboratory while each service would select one of their existing MRF's to serve as the principal applications laboratory for their service. These recommendations imply laboratory consolidation within each service with continuing investment in the remaining facilities.

Implementation of our recommendations will provide a sound basis for maintaining adequate microelectronic research generic to defense application under declining budgets as we move into the uncertain post cold war era.

We want to make special mention of the outstanding contributions made by the Executive Secretary, and the fine assistance provided by the government advisors.

William G. Howard *Albert Narath* *Frank A. Brand*
William G. Howard Albert Narath Frank A. Brand
Chairman Vice Chairman

Michael Ettenberg
Michael Ettenberg

Robert J. Hermann
Robert J. Hermann

W.J. Kitchen
W.J. Kitchen

Attachment

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

During its deliberations, the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories questioned plans to create a new microelectronics facility as part of the Army Research Laboratory and suggested a panel be formed to assess the future of DoD's microelectronics facilities. The Defense Science Board Task Force on Microelectronics Research Facilities was formed in response to this request.

Specific issues for the task force included:

- Missions of existing Service microelectronics research facilities and the extent of their Service uniqueness;
- Processes for their support of acquisition;
- Capital investment needed for maintaining state-of-the-art facilities;
- Wisdom of establishing a single microelectronics research facility, and secondarily, advantages and disadvantages of having that facility be Government-Owned, Contractor-Operated (GOCO).

The Task Force adopted a broad definition of the microelectronics field including conventional integrated circuits, microwave devices, and photonics.

The Task Force agreed upon the following perspectives to guide the inquiry:

- Microelectronics is a pervasive enabling technology for military systems;
- To serve the full range of Defense needs, DoD should have both internal and external (industrial) microelectronics competence;
- DoD microelectronics research facilities internally should focus most attention on the application of microelectronics technology to systems;
- Industry should be the provider of most microelectronics capability for Defense applications. However, DoD needs in-house research facilities to support internal competence and to support defense technologies that lie outside industrial interest; and
- The cost of capital equipment and facilities support will increase faster than inflation.

The Mission of DoD microelectronics research facilities was defined:

- To maintain "smart buyer" competence;
- To assure industrial capability for Defense applications;

- To stimulate, adapt, acquire, and create state-of-the-art microelectronics science and technology;
- To couple advanced microelectronics to collateral technologies;
- To preserve and develop DoD core competence.

The Task Force developed a range of possible structures and rated them using these mission elements as evaluation factors. From this evaluation and attendant discussion, it concludes:

- A single DoD microelectronics research facility would create barriers to interactions with system users and impair the ability to apply microelectronics technology.
- GOCO operations are more limited in interactions with system developers and users than Government staffed facilities.
- The application of microelectronics to military systems is best served by facilities familiar with those systems and Service procedures. The number of microelectronics research facilities in the Services can be reduced through consolidation: one applications oriented research facility, selected from among existing facilities, is necessary and sufficient for each Service. Continued investment in these facilities will be required.
- A broad range of microelectronics science and technology is common across the Services. A single corporate microelectronics research facility working on these issues is necessary and sufficient. The Naval Research Laboratory (NRL) microelectronics research facility can best serve this function.
- Reducing the number of microelectronics research facilities to four (three Service applications facilities and one corporate facility) will use resources more effectively consistent with Service missions and provide a critical mass necessary to maintain program quality.
- An appropriately sized state-of-the-art research facility for Government use (estimated initial cost of \$50M in equipment and \$26.5M in building and facilities) is projected to require about \$28M recurring cost of operation. Such a facility would support the efforts of approximately 150-250 scientists and engineers.
- The Tri-Service Reliance process should be extended to cover facilities and equipment and should be used to assure that the programs of the Service applications microelectronics research facilities and the corporate microelectronics research facility meet the needs of all three Services.

The Task Force further recommends:

- A balance between internal and external work at each microelectronics research facility.
- Annual review by outside experts of the corporate microelectronics research facility.

INTRODUCTION

Notes

During the course of its study, the Task Force visited DoD microelectronics research facilities as detailed in Appendix D. In addition, we requested data from many of these facilities. Out of respect for our hosts and colleagues in the laboratory system, we caution the reader not to interpret our recommended practices to mean that no one is already doing them. Often, our recommendations are presently in force at one or more of these facilities, and thus should be taken as support for these efforts, as encouragement for use at all microelectronics research facilities, and as support for continuation or expansion of these practices in the future.

The term DoD as used in this study includes the Military Departments, Defense Agencies, and all other Department of Defense Components.

Task Force Mission

During its deliberations, the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories questioned plans to create a new microelectronics facility as part of the Army Research Laboratory and suggested a panel be formed to assess the future of DoD microelectronics facilities. (The Terms of Reference for the Study are found in Appendix A; Membership in Appendix B).

Specific issues for this panel include but are not limited to:

1. The established missions of the Service microelectronics research facilities and the extent to which they are Service unique.
2. The process by which the Service microelectronics research facilities support the acquisition process
 - a) Tools and techniques to support Service goals in electron devices, subsystems and systems.
 - b) Mechanisms to transfer microelectronics technology from the laboratory to military systems.
 - c) Optimizing the early choice of appropriate technologies in military systems to prevent program delays and cost overruns.
3. The extent continued capital investment will be required to maintain state-of-the-art microelectronics research facilities.
4. The advantages and disadvantages of a single microelectronics research facility to meet the needs of all three Services. If a single facility is a viable solution, consider the advantages and disadvantages of a Government-Owned, Contractor-Operated facility.

Structure of the Study

The structure of this report mirrors the Task Force study activities:

- Definition of the study's scope (especially interpretation of the terms "microelectronics" and "research facility");
- Discussions with the Service science and technology executives regarding current Service organization, practices and plans, (summarized in Appendix C) and principals directing the Tri-Service Reliance process;
- Visits to existing DoD microelectronics facilities and to two contractor-operated facilities (summarized in Appendix D);
- Establishment of study precepts and microelectronics research facility mission and attributes;
- Development of a proposed structure and transition (alternatives considered are outlined in Appendices E and F) and implementation.

The Task Force developed additional supporting cost and investment material based on the experience of its members -- (these data are presented in Appendix G).

Definitions

The scope of the panel's considerations is defined as:

Microelectronics

Devices - electron devices, including discrete, IC, microwave and photonic devices, displays, and sensors

Technologies - electronic materials, processes, devices, design, packaging, applications

Activities - in-house research and development and insertions into systems applications

Research Facility

- A geographically consolidated organization whose personnel spend at least 10 per cent of total applied work-years in S&T budget categories 6.1, 6.2 and 6.3a and at least 50 per cent of total applied work years in all research, development, test and evaluation categories.
- Whose capabilities include materials growth and solid state device processing and fabrication. Operations having only analytical, design and/or test and evaluation capabilities are not considered microelectronics research facilities for the purposes of this study.
- Not predominantly a production facility.

Principal Existing Government Facilities

Army: ETDL - Fort Monmouth, NJ *,+
 HDL (planned ARL)- Adelphi, MD *,+
 NVEOL - Fort Belvoir, VA *,+

Navy: NRL - Washington, DC *,+
 NCCOSC - RDT&E Division, San Diego, CA *,+
 NAWC- Weapons Division, China Lake, CA
 NAWC - Aircraft Division, Indianapolis, IN
 NSWC - Crane Division, Crane, IN

Air Force: Wright Lab - Dayton, OH *,+
 Rome Lab - Lincoln, MA *,+
 Phillips Lab - Albuquerque, NM *
 ALC - Sacramento, CA

Others: MIT Lincoln Labs - Lincoln, MA *,+
 NSA SPL/MRL - Fort Meade, MD +
 Miscellaneous (JPL, Aerospace,
 DOE/Sandia +, DOE/Livermore,
 NASA/MSFC, NIST)

* Locations found to have substantial DoD 6.1, 6.2, and/or 6.3a
microelectronics activities.

+ Locations visited by the Task Force.

PERSPECTIVES

Microelectronics is a Pervasive Technology

Finding:

Based on the experience of its members, many critical technology studies, and the material presented to it, the Task Force agrees that microelectronics is a pervasive enabling technology for Defense systems.^{1,2} Electronics-based military systems proved their utility during Operation Desert Storm. Microelectronics is an essential element of all seven DoD technology thrust areas and many Service specific applications.

Microelectronics technology continues to progress rapidly across a broad technical front and offers the promise of further significant improvements in military system performance and supportability.³

New microelectronics technologies and their applications do not come about of their own accord. They often require someone to make the link between technology and application opportunity and frequently must be "sold" to the systems developer. The sale must be supported by demonstration, reliability, cost, performance and producibility experience.

Conclusion:

DoD needs a strong microelectronics science and technology program which encourages diversity and innovation in all phases from research through system development and support. The objective of this program should be to assure Defense Department access to and insertion of microelectronics technology to support its needs.

¹DoD Critical Technologies Plan", 1989, 1990 and 1991

²"Report of the National Critical Technologies Panel", March 1991, Office of Science and Technology Policy

³Report of The Defense Science Board 1981 Summer Study Panel on Technology Base, Nov 1981

Microelectronics R&D Capital Costs Will Increase

Finding:

The need to keep up with the rapid rate of change of microelectronics technology, both in laboratories and applications, forces continual retooling of microelectronics facilities. Although they depreciate in value to their mission at a slower rate than production tools, the cost of tools and facilities to do microelectronics research, development, and application continues to escalate. Defense resources for existing microelectronics research facilities, even if modestly increased, are unlikely to keep pace with the costs to stay current. Inability to keep up with the increasing costs of capital equipment, maintenance and operations has the potential to limit or degrade the current Defense microelectronics program. (See Appendix G)

Conclusion:

DoD must plan to update continuously its microelectronics facilities and equipment to avoid falling behind the state of the art in important technical areas. Funding constraints require improved efficiency in use of this equipment and some measure of consolidation. The number of DoD microelectronics research facilities currently in operation should be reduced to concentrate operations and improve efficiency and effectiveness consistent with DoD and Service needs.

DoD Needs Internal and External Microelectronics Competence

Finding:

Much of the microelectronics technology and hardware needed for military systems can be supplied by commercial sources⁴ where the scale of resources far outstrips Defense-stimulated needs. However, many important technology areas lie outside the sphere of industrial interest,⁵ either because of a lack of commercial customer pull or because the technology is too risky or has too long term potential payoff for industrial firms to make substantial investment.⁶

Conclusion:

The DoD microelectronics science and technology program should have both internal and external activities which serve to build applications competence for existing industrial microelectronics technologies and to create new technologies where industrial interest and ability are lacking.

⁴Bingaman, Gansler, and Kupperman, "Integrating Commercial and Military Technologies for National Strength", Center for Strategic and International Studies, 1991

⁵"Report of the Defense Science Board Task Force on Defense Semiconductor Dependency", Feb 1987

⁶Office of Technology Assessment, "Holding the Edge: Maintaining the Defense Technology Base", 1989

Need for In-House Microelectronics Research Facilities

Finding:

DoD's electron devices needs extend well beyond commercial industrial capabilities in many mission-critical areas. The ability to conduct process and device research and development (e.g., for materials such as silicon carbide for high temperature jet engine controls, compound semiconductor materials for on-chip optical sources, heterostructures for infrared detectors and microwave and millimeter-wave devices) promises development of high leverage microelectronics capability for military systems well before commercial demands.⁷

The rapid expansion of knowledge and know how in microelectronics science and technology requires actual participation in the performance of research and development by the Services to be fully informed and capable of performing as the "smart buyer".

In addition, recruiting and sustaining a highly competent and current staff qualified to carry out the "smart buyer" and technology adaptation and creation functions of the microelectronics research facility are greatly enhanced by the opportunity to do hands on work, which in turn requires access to a DoD fabrication capability.

Conclusion:

DoD should continue to have its own internal microelectronics research capability, including the ability to fabricate electron devices and circuits.

Focus on Applications

Finding:

Others have observed⁸ that we as a nation appear better at inventing new technologies than of efficiently applying them. Long delays in incorporation of new microelectronics technology in military applications lends weight to this observation.

Conclusion:

The Department of Defense and its Components should focus most of their microelectronics science and technology attention and resources on applications to military products and systems. This means that microelectronics research facilities should emphasize the insertion of new technology that increases capability, i.e., performance, reliability, and lower cost, into DoD systems.

⁷Office of Technology Assessment, "Holding the Edge: Maintaining the Defense Technology Base", 1989

⁸Council on Competitiveness, "Gaining New Ground: Technology Priorities for America's Future", 1991

THE DOD MICROELECTRONICS RESEARCH FACILITY SYSTEM

The Task Force view of an appropriate DoD microelectronics research facility system is described below:

Mission

The Task Force summarizes the mission of microelectronics research facilities in five parts (listed in priority order):

Maintain "Smart Buyer" Competence for Microelectronics

Encourage competence and involvement needed to make the Services/DoD a "smart buyer" of microelectronics for system applications.

The microelectronics research facility must:

- Maintain a competent, up to date staff
- Participate in creation of new system concepts
- Participate in acquisition processes
- Advocate new microelectronics technologies
- Support the logistics process
- Be concerned with producibility issues
- Support and exploit external R&D activities effectively

Assure an Industry Defense Microelectronics Capability

Promote industrial production capability to support military microelectronics needs and encourage industrial developments to meet military requirements.

Stimulate, Adapt, Acquire and Create State-of-the-Art Microelectronics Science and Technology

Seek a microelectronics capability needed for current or future systems wherever it resides; acquire and adapt the competence needed to apply it effectively; stimulate or create new technology where the task is too large for universities and too long-term or too specialized for industry.

Couple Advanced Microelectronics Capabilities to Collateral Technologies

Capitalize on the exploitation of collateral technologies. Collateral technologies are other research disciplines that require a microelectronics capability (e.g., computer systems and architecture, communications, fuzing, radar, electronic warfare, ...). Examples of this coupling include integration of technologies into systems such as that done by the USAF for the F-22, the Army for advanced missile fuzes (PATRIOT) and artillery systems such as the Multiple Option Fuze Artillery (MOFA), and the Navy for Airborne Shared Apertures.

Preserve and Develop DoD Microelectronics Core Competence

Provide the environment and facilities for developing and maintaining expertise and experience in microelectronics:

- Train future military and policy leaders in technology management
- Train future technical leaders
- Encourage an understanding of microelectronics in other disciplines
- Maintain the ability to do "diving catches," i.e., solve critical problems quickly

Attributes

The Task Force identified several attributes critical to the effective performance of the mission of DoD microelectronics research facilities:

Competence

- A competent technical staff, knowledgeable of both the science and technology aspects of microelectronics, sufficiently flexible to change with technology shifts, eager to exploit new opportunities, and able to do R&D at the bench
- Access to the practice of microelectronics fabrication and design
- Frequent interactions with leading industrial and academic workers in the field
- Preservation of past DoD and industry experience and lessons learned
- Ability to address producibility and experimental prototype issues
- Ability to develop new solutions to important problems--ability to do "diving catches" to solve unforeseen microelectronics technology problems in the critical path
- Knowledge of and close coordination with key system requirements

Range of Activities

- A healthy balance of internal and external R&D activities
- Coverage of 6.1 to 6.3a activities, and downstream engineering support including some 6.4 and 6.5 where it is the first or key insertion of a new technology

Strong Connections to Other DoD Activities

- Close working relationship with systems development and deployment programs
- Routine participation in the "smart buyer" functions
- An advocate for insertion of appropriate microelectronics technology
- Good communication with scientists and engineers working in other fields

Strong Industrial Connections

- Stimulate technology developments in industry appropriate to meet Defense needs
- Promote industrial capability to manufacture Defense microelectronics needed during national emergencies
- Assure high quality industrial support of Defense through expert and objective involvement in the procurement process.

Organization and Structure

A Single DoD Microelectronics Research Facility

Finding:

The three Military Departments develop systems to accomplish their own missions using their own development practices. While underlying technologies are similar, each Service has legitimate, unique microelectronics engineering support requirements. Industrial and Defense experiences show that effective microelectronics technology application requires mutual understanding of the mission environment, proficiency in tailoring technology to meet system requirements and the ability to work closely with the acquisition system. A single DoD microelectronics research facility will be less effective at applying microelectronics technology than a system of Service microelectronics research facilities attuned to the Service mission, acquisition environment, and requirements.

In addition, many military needs can be met by more than one microelectronics technology approach. For instance, infrared focal plane arrays can be based on HgCdTe compound semiconductor or PtSi detectors. Currently within DoD, the former has been developed by the Army and the Navy, the latter by the Air Force - both technologies have performance and cost advantages, depending upon the specific application. A single DoD microelectronics research facility will have problems developing diverse but similar technologies to the point where the applications advantages can be understood.

Conclusion:

The DoD microelectronics research facility system should include multiple facilities able to address unique Service needs.

Government-Owned, Contractor-Operated Facilities

Findings:

The Task Force found no compelling reason for converting microelectronics research facilities to contractor-operated facilities. Although contractor-operated facilities can have outstanding research and development capabilities, the Task Force found potential impediments to contractors fulfilling the broad spectrum of microelectronics research facilities mission activities which may involve inherently Government functions⁹ such as procurement^{10,11}, program evaluation, interaction with Government systems developers, as well as interactions involving industrial proprietary information. Besides hindering important "smart buyer" functions, conversion of all microelectronics research facilities to GOCO's could deprive DoD of a source of potential technical managers and leaders with Government experience in microelectronics research and applications.

Conclusion:

DoD microelectronics research facilities should be Government-operated.

Applications Microelectronics Research Facilities

Need

Finding:

Applications of microelectronics require a wide range of Service-unique and system-specific knowledge with some applications being common.

Conclusion:

The core of the DOD microelectronics research facility system should be three applications microelectronics research facilities within the Military Departments. Each Military Department should select from among existing principal microelectronics research facilities a single applications microelectronics research facility closely associated with the development, logistics and user communities.

⁹Draft Policy Letter 91-____, "Inherently Governmental Functions"

¹⁰OMB Circular No A-76 (1983), "Performance of Commercial Activities"

¹¹OMB Circular A-109

Role

The role of the applications microelectronics research facilities, within the context of the overall mission (Page 9), is to have primary responsibility for applying microelectronics technology to the system needs of the Military Departments. They act with their Service's development organizations¹² and those of other Services, as well as the corporate microelectronics research facility to help insert appropriate microelectronics technology into current and future systems. They translate microelectronics application needs into device and technology requirements and articulate them to industry, interacting with industrial microelectronics technology developers and users to promote commonality.

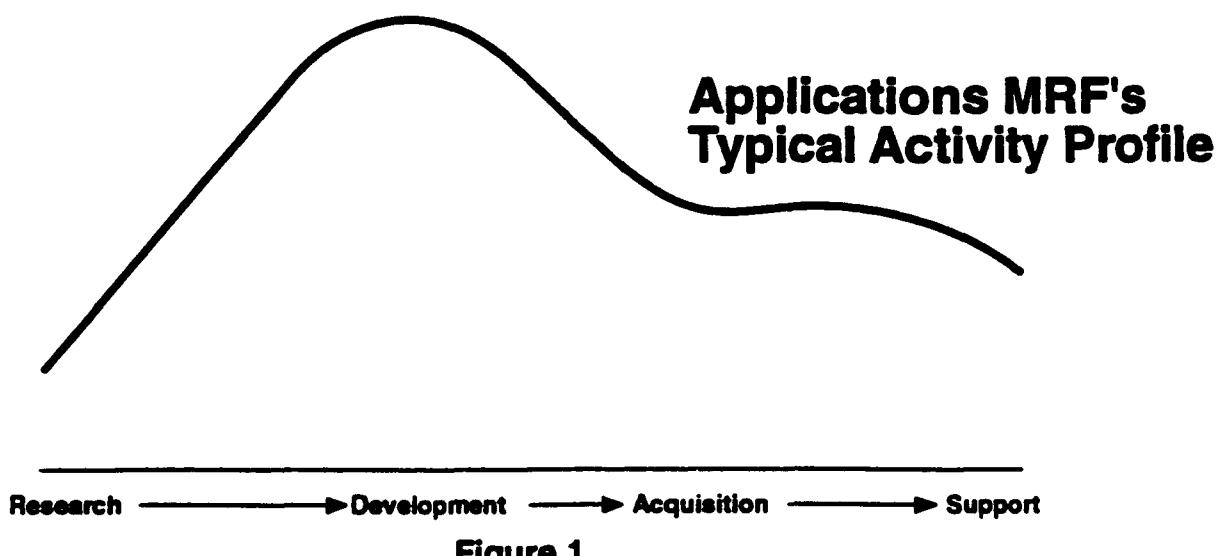
Program Planning and Funding

Finding:

A viable applications microelectronics research facility requires a full spectrum of research activities. The Task Force was impressed by the involvement of AFOSR, ONR and ONT in advocating and supporting in-house microelectronics research and exploratory development activities at Wright Laboratory, NCCOSC, and the Naval Research Laboratory and by the industrial funding concept employed by the Navy. The Task Force recognizes that Service customers will focus on activities that lie at the technology demonstration/systems support end of the R&D spectrum.

Conclusion:

Service applications microelectronics research facilities should be supported, for the most part, by "customer" organizations having systems microelectronics needs in research and development, manufacturing technology, and production and logistics support. The Service research and technology offices should support more exploratory activities and provide "seed" funds for new technology options to enable the continuous technological growth of these facilities. Figure 1 illustrates a range of potential funding profiles for the applications microelectronics research facilities; the funding profile may differ according to Service practice.



¹²Army Research/Development Engineering Centers (RDECs), Navy Warfare Centers, Air Force Product Divisions

Corporate Microelectronics Research Facility

Need

Finding:

There are long range microelectronics technology needs of the Department of Defense which will not be addressed, wholly or in part, by the civilian commercial market--either because they are unique or far ahead of those of non-military microelectronics technology users. These areas change with time. (See Perspectives for current examples.) Further, a broad spectrum of basic microelectronics science and technology is common to many Defense applications.

Conclusion:

To fill this gap, one Tri-Service corporate microelectronics research facility serving the needs of all DoD is necessary and sufficient.

Role

The corporate microelectronics research facility is to be the long range microelectronics research and development arm of the Military Departments and Defense Agencies. In accord with the mission, it conducts the science and technology base for the microelectronics needs of the Department of Defense. It seeks new high leverage microelectronics technologies for Defense applications. By exception, it conducts technology application activities in response to requests from the Military Departments and Defense Agencies.

Program Planning and Funding

Finding:

The corporate microelectronics research facility serves all three Services as well as the Defense Agencies.

Conclusion:

The technical program of the corporate microelectronics research facility should be coordinated with the full range of potential military needs. Tri-Service and OSD involvement in program planning is essential to its effectiveness in meeting this mission. A Board of Directors, appointed by the DDR&E and the Military Departments, should approve the overall plans and review the accomplishments of the corporate microelectronics research facility. Funding is primarily from basic research and exploratory development (6.1 and 6.2) budget accounts with a small amount of advanced development (6.3a) funding. Figure 2 illustrates a potential funding profile for the corporate microelectronics research facility.

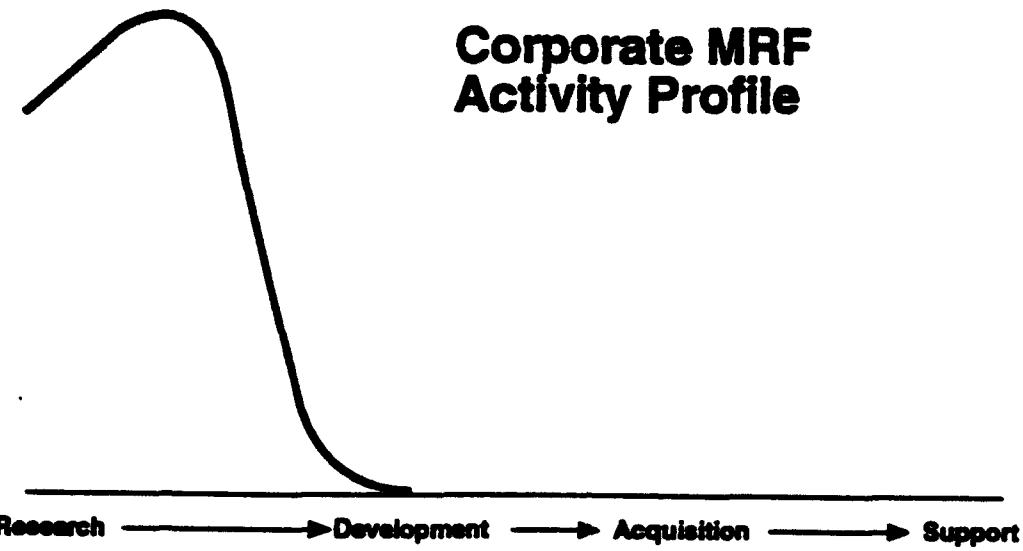


Figure 2

Communications in the DoD Microelectronics System

Finding:

The in-depth knowledge required for effective application of advanced microelectronics technologies to military systems and to other research disciplines requiring microelectronics expertise requires outreach and a close working relationship between microelectronics experts and systems engineers. Physical proximity is a strong enabler of this kind of relationship; microelectronics research facilities cannot be located next to each military systems development operation.

Conclusion:

Although this study supports consolidation of DoD microelectronics research facilities for materials growth, processing, and device fabrication, consolidation of all in-house microelectronics expertise is not desirable. DoD microelectronics user organizations should maintain their own microelectronics expertise but not maintain or acquire electronic materials growth and device processing facilities. To assure the mission effectiveness of the applications microelectronics research facilities, expert technical representatives (applications oriented engineers) from these facilities should be tasked to work closely with applications and other research organizations.

Finding:

Successful microelectronics research requires that the microelectronics research facilities work closely with each other and also with other technology research and development disciplines, both to support the microelectronics effort (e.g., computer architecture or electronic materials growth) and to couple microelectronics technology to potential applications areas.

Conclusion:

Besides formal project coordination, staff rotation between the corporate microelectronics research facility and the Service applications microelectronics research facilities is an important means of tying the technical activities together.

Cost, Size and Staff

Each microelectronics research facility should be sized to provide the minimum internal effort required to maintain a critical mass of core competence in the technology areas to be covered. The Task Force projected that each of the four microelectronics research facilities would consist of facilities and equipment with a current capital cost of approximately \$26.5M and \$50M, respectively. A facility of this sort could support the internal research activities of between 150 and 250 total technical personnel (scientists, engineers, technicians, on-site contractors and Government employees). The operating costs of such a facility including depreciation of building, facilities, and equipment would be about \$28M annually. These estimates are based on industry experience and accounting. The assumptions and the model are described in Appendix G.

Management

Tri-Service Reliance process

Finding:

Coordination and communication within the Department of Defense are important to microelectronics research and development program efficiency, effectiveness, and quality. The Tri-Service Reliance process has been a positive step in setting up effective coordination. It provides one means to serve this function. Progress thus far in Reliance efforts to rationalize Service microelectronics development programs is encouraging, but even more can be done.

Conclusion:

The scope of Reliance should be strengthened and extended to include facilities and equipment. The Reliance mechanism should be used to coordinate the activities of the Service microelectronics applications and corporate microelectronics activities through review of major program elements and assessment of technology coverage rather than review of individual programs. The interaction should be expanded to include microelectronics activities of Defense Agencies. The relationship to OSD should be formalized.

Microelectronics Research Facilities Quality

Finding:

DoD in-house quality and relevance are enhanced by comparison and constant interaction with industrial, academic, and Government peers. Evaluation of DoD activities by outside peers offers an independent assessment of their effectiveness and opportunity for introduction of new ideas.

Conclusion:

A program of routine, periodic assessment of DoD microelectronics research facility activities by outside (non DoD) experts should be established to help assure their continued vitality and relevance. In addition, the Military Department Offices of Research, (ARO, ONR, and AFOSR) should be involved in evaluating and comparing work done at the corporate microelectronics research facility with that performed outside the Government.

Internal/External Microelectronics Research Facilities Program Balance

Finding:

Internal and external program activities are important to maintaining an effective microelectronics research facility program. Internal projects provide the means to recruit and sustain a competent technical staff and to pursue technology developments and evaluations of interest to DoD and the Services. External projects, on the other hand, provide disciplined contact between in-house scientists and engineers and the outside R&D community, encourage industrial microelectronics developments to meet military needs, and offer flexibility to adjust to rapid technological changes that would otherwise require substantial internal facilities or equipment modifications.

Conclusion:

Microelectronics research facilities within DoD should seek to balance in-house and out-of-house technology development.

TRANSITION

The transition from today's DoD microelectronics research and development system to the one proposed in this report requires specific actions by the Military Departments and by the Office of the Secretary of Defense. In accomplishing this transition, primary emphasis should be placed on maintaining microelectronics expertise in the research and development program and in providing expert support during the entire system life cycle. In the microelectronics facilities visited, high quality people formed the core resource. Implementation activities should make the best use of this resource, minimize the disruption of their support to the Services, and be managed to assure professional treatment for the personnel affected.

Applications Microelectronics Research Facilities

Finding:

Each Service has established microelectronics facilities to meet its own needs. Consequently, multiple research, prototyping and repair facilities are in operation within each Service. Each Service already has a *de facto* principal microelectronics research facility with a broad range of microelectronics capabilities.

Conclusion:

Each Service should act to establish and designate its applications-oriented microelectronics research facility. Transition from the present multiple facility organization to the consolidated system recommended in this report could be accomplished by limiting new investments in fabrication equipment at other applications microelectronics research facilities, by carrying out over time an orderly transfer to the designated facility of microelectronics research programs requiring fabrication equipment, and by establishing procedures for interchange and interaction of personnel between the designated facility and microelectronics organizations in sister organizations. (This consolidation of microelectronics processing capabilities is not intended to apply to analytical, test and evaluation, or design activities.) Each Service should prepare a plan for consolidating its microelectronics research facilities and supporting the designated facility.

The Tri-Service Corporate Microelectronics Research Facility

Finding:

One DoD microelectronics research facility already exists with the kind of long range perspective required for the Tri-Service corporate microelectronics research facility -- the Naval Research Laboratory. In addition, plans have been made to establish an Army counterpart facility at the Army Research Laboratory. The Air Force has no plans for an equivalent corporate facility.

Conclusion:

Given its long history of successful electronics research, its established technical staff and physical capabilities, its experienced management, and the presence of supporting technological activities in materials, chemistry and computer systems, the Task Force concludes that NRL can best serve as the Tri-Service corporate microelectronics research facility.

The NRL facility does not appear to require a major expansion to adapt to this new corporate mission, although some additional growth can be expected to accommodate other Service needs and technical personnel. The Task Force concludes that investment to build additional corporate microelectronics research facilities is unwarranted.

The management of the Tri-Service corporate microelectronics research facility is best assigned to the experienced management of NRL. The transition process and long-term management plan for the Tri-Service corporate microelectronics research facility should be developed by a task force representing the DDR&E, the Military Departments, and the relevant Defense Agencies. The management plan, to be submitted to the DDR&E for approval, should include the charter for the corporate microelectronics research facility, program coordination and direction, accommodation of personnel from the Army and the Air Force, and funding. The plan should assure that the implementation of the Tri-Service corporate microelectronics research facility does not redirect resources from the Service applications microelectronics research facilities, resulting in their loss of critical mass and competence.

IMPLEMENTATION ACTIONS

The USD(A) should:

Consolidation Actions:

Direct the Service Acquisition Executives to consolidate microelectronics research facilities into a single applications microelectronics research facility each, focused on applications needs throughout the respective Service. Service plans for this consolidation should be submitted to the DDR&E for approval.

Base Realignment and Closure (BRAC) planning:

Submit inputs to the BRAC as necessary to carry out decisions arising from this study.

Extension of Tri-Service Reliance Responsibilities

Extend the Tri-Service Reliance process to address microelectronics equipment and facilities and also the coordination of the programs of the applications microelectronics research facilities and the corporate microelectronics research facility.

Define and articulate the relationship of OSD and Reliance.

The DDR&E should:

Transition Planning

Establish and task a Task Force with representatives from OSD, the Military Departments, and Defense Agencies to prepare a transition and management plan for the corporate microelectronics research facility described earlier.

Review and approve the corporate microelectronics research facility plan prepared by the Task Force.

Consolidation Actions

Review and approve the Service microelectronics research facility consolidation plans.

External/Internal Program Balance

Direct that each of the microelectronics research facilities maintain a balanced program of internal and external research and development.

External Review of Internal Program

Direct the Tri-Service corporate microelectronics research facility to incorporate routine program reviews by peers from outside the DoD.

APPENDIX A

TERMS OF REFERENCE



THE UNDER SECRETARY OF DEFENSE
WASHINGTON, DC 20301

8 FEB 1992

ACQUISITION

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference (TOR) -- Defense Science Board (DSB)
Task Force on In-House Microelectronics Research
Facilities

You are requested to organize a DSB Task Force to assess the advantages and disadvantages of a single microelectronics research facility for the Department of Defense.

Public Law 101-510 established the Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories to study the Department of Defense (DoD) laboratory system and provide recommendations to the Secretary of Defense on the feasibility and desirability of various means to improve the operation of the DoD laboratories. Among the means the commission was directed to study were:

(1) conversion of some or all of the DoD laboratories to Government-Owned, Contractor-Operated laboratories, (2) mission and/or function modification of some or all of the laboratories, and (3) consolidation or closure of some or all of the laboratories.

As part of its laboratory consolidation plans, the Army proposed and the Commission supported forming the Combat Material Research Laboratory (now known as the Army Research Laboratory) to be located primarily at Aberdeen and Adelphi, Maryland. Under this proposal, various electronics research and development elements of Army laboratories and development centers would be consolidated at Adelphi, Maryland, and a state-of-the-art microelectronics research facility would be constructed there.

In view of the cost of this facility and pervasive applications of microelectronics in weapon systems of all types and the rapid advances continuing to be made in this technology, the Commission questioned this portion of the Army plan, and put forth the following recommendation:

An independently appointed review group should assess the advantages and disadvantages of a single microelectronics research facility for all three Services. If a single facility is a viable solution, consideration should be given to a Government-Owned, Contractor-Operated laboratory.

The recommended study must be completed within five months to avoid additional costs should the Army proceed as planned.

Issues to be addressed by the Task Force include, but are not limited to:

1. The established missions of the Service microelectronics research facilities and the extent that they are Service unique.
2. The process by which the Service microelectronics research facilities support the acquisition process.
 - a) Tools and techniques to support Service goals in electron devices, subsystems and systems.
 - b) Mechanisms to transfer microelectronic technology from the laboratory to military systems.
 - c) Optimizing early choice of appropriate technology in military systems to prevent program delays and cost overruns.
3. The extent continued capital investment will be required to maintain state-of-the-art microelectronics research facilities.
4. The advantages and disadvantages of a single microelectronics research facility to meet the needs of all three Services. If a single facility is a viable solution, consider the advantages and disadvantages of a Government-Owned, Contractor-Operated facility.

The Director, Defense Research and Engineering will sponsor the Task Force. Dr. William Howard will serve as Chairman. Dr. Susan Turnbach will be the Executive Secretary, and COL Elray P. Whitehouse, USA, will be the DSB Secretariat Representative. It is not anticipated that your inquiry will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code.



Don Yockey

APPENDIX B

MEMBERSHIP

APPENDIX B

DEFENSE SCIENCE BOARD TASK FORCE ON MICROELECTRONICS RESEARCH FACILITIES

Chairman

Dr. William G. Howard, Jr.
Private Consultant

Vice Chairman

Dr. Albert Narath
President
Sandia National Laboratories

Task Force Members

Dr. Frank A. Brand
Private Consultant

Dr. Michael Ettenberg
Vice President
Solid State Division
David Sarnoff Research Center

Dr. Robert J. Hermann
United Technologies Corporation

Dr. W. J. Kitchen
Vice President
Motorola Semiconductor Products Sector

Executive Secretary

Dr. Susan E. Turnbach
Office of the Director, Defense Research & Engineering / MS&ED

DSB Military Assistant

Colonel Elray P. Whitehouse, USA
Office of the Under Secretary of Defense / DSB

Government Advisors

Dr. Gerald Borsuk
Naval Research Laboratory

Dr. John M. MacCallum
Office of the Secretary of Defense

Mr. William Edwards
Wright Laboratory, Wright-Patterson AFB

Mr. Jerry Reed
Harry Diamond Laboratory

Staff

Mr. Steven L. Arledge
Science Applications International Corp.

Mr. Edward J. Burke
Science Applications International Corp.

APPENDIX C

ORGANIZATION AND PRACTICES OF THE SERVICES IN RESEARCHING, DEVELOPING AND APPLYING MICROELECTRONICS TECHNOLOGY

APPENDIX C

ORGANIZATION AND PRACTICES OF THE SERVICES IN RESEARCHING, DEVELOPING AND APPLYING MICROELECTRONICS TECHNOLOGY

The Task Force noted that significant internal research and development capabilities relative to microelectronics and device technology presently exist within each of the Services. Visits to several of the in-house facilities confirmed initial impressions that the Services have a basic commonality of mission, but also brought out the differences in technology emphasis, reporting mechanisms and organization.

- a. Regarding mission, all are intended to:
 - Provide for R&D of high-leverage, breakthrough technologies for military systems
 - Conduct scientific research and extend scientific knowledge of interest to the military
 - Provide the technology for an improved logistics supply of microelectronic parts and technology update to avoid electronics obsolescence
 - Assist industry and academia in retaining or regaining the Nation's competence in microelectronics.
- b. Microelectronics research is concentrated at the following facilities:
 - Army
 - Electronics Technology and Devices Laboratory, Ft. Monmouth, New Jersey
 - CECOM Center for Night Vision and Electro-Optics, Ft. Belvoir, Virginia
 - Harry Diamond Laboratory, Adelphi, Maryland
 - Navy
 - Naval Research Laboratory, Washington, D.C.
 - Naval Command Control and Ocean Surveillance Center, RDT&E Division (formerly Naval Ocean Systems Center), San Diego, California
 - Air Force
 - Wright Laboratory, Dayton, Ohio
 - Rome Laboratory, Lincoln, Massachusetts
- c. Technology Emphasis:

Army microelectronics work occurs primarily at three locations. Harry Diamond Lab in Adelphi, Maryland concentrates on basic research, while the Electronics Technology and Devices Lab at Fort Monmouth, New Jersey, and the

Night Vision and Electro-Optical Directorate at Fort Belvoir, Virginia, cover the spectrum of R&D activities. The Naval Research Laboratory in Washington, DC is the Navy's single integrated corporate laboratory for scientific research and advanced technology development and performs broad based multidisciplinary microelectronics R&D. Technology base research and development and system related applications work are performed at the multi-purpose microfabrication, materials, and packaging facility at the Naval Command, Control and Ocean Surveillance Center (NCCOSC) in San Diego, California. Air Force microelectronic fabrication is concentrated at Wright Laboratory, although strong device technology exists at Rome Laboratory. The Wright Laboratory activities cross all research and development fields and while closely connected to avionics applications, they are broadly supportive of all Air Force systems.

d. Each Service is performing semiconductor R&D in a variety of technologies and has fostered the development of academic and commercial industrial teams to satisfy the particular needs of that service. The scientists and engineers in each Service are involved with the processes used by these separate commercial enterprises through cooperative, joint, and contract programs -- all of which help facilitate technology transfer.

e. Organizationally, as shown in Figs. C-1, 2, 3, the Service labs follow a variety of reporting chains. In the Army, both ETDL and HDL report directly to Army Material Command through Army Laboratory Command, while NVEOD reports to Army Material Command through the Communications Electronics Command. The Army's proposed plan for an Army Research Laboratory would concentrate S&T activities at that facility at Adelphi, Maryland.

The Naval Research Laboratory reports through the Chief of Naval Research to the Assistant Secretary of the Navy (Research, Development, and Acquisition). The RDT&E (NRaD) Division of NCCOSC reports to the Chief of Naval Operations through the Space and Naval Warfare Systems Command.

The primary Air Force microelectronics facilities at Wright and Rome report through the Aeronautical and Electronic Systems Divisions, respectively, to Air Force Systems Command (Air Force Material Command on July 1, 1992).

Attachment 1 provides a summary of the characteristics of existing Service microelectronics research facilities.

MICROELECTRONICS FACILITY ORGANIZATIONAL STRUCTURE

- ARMY -

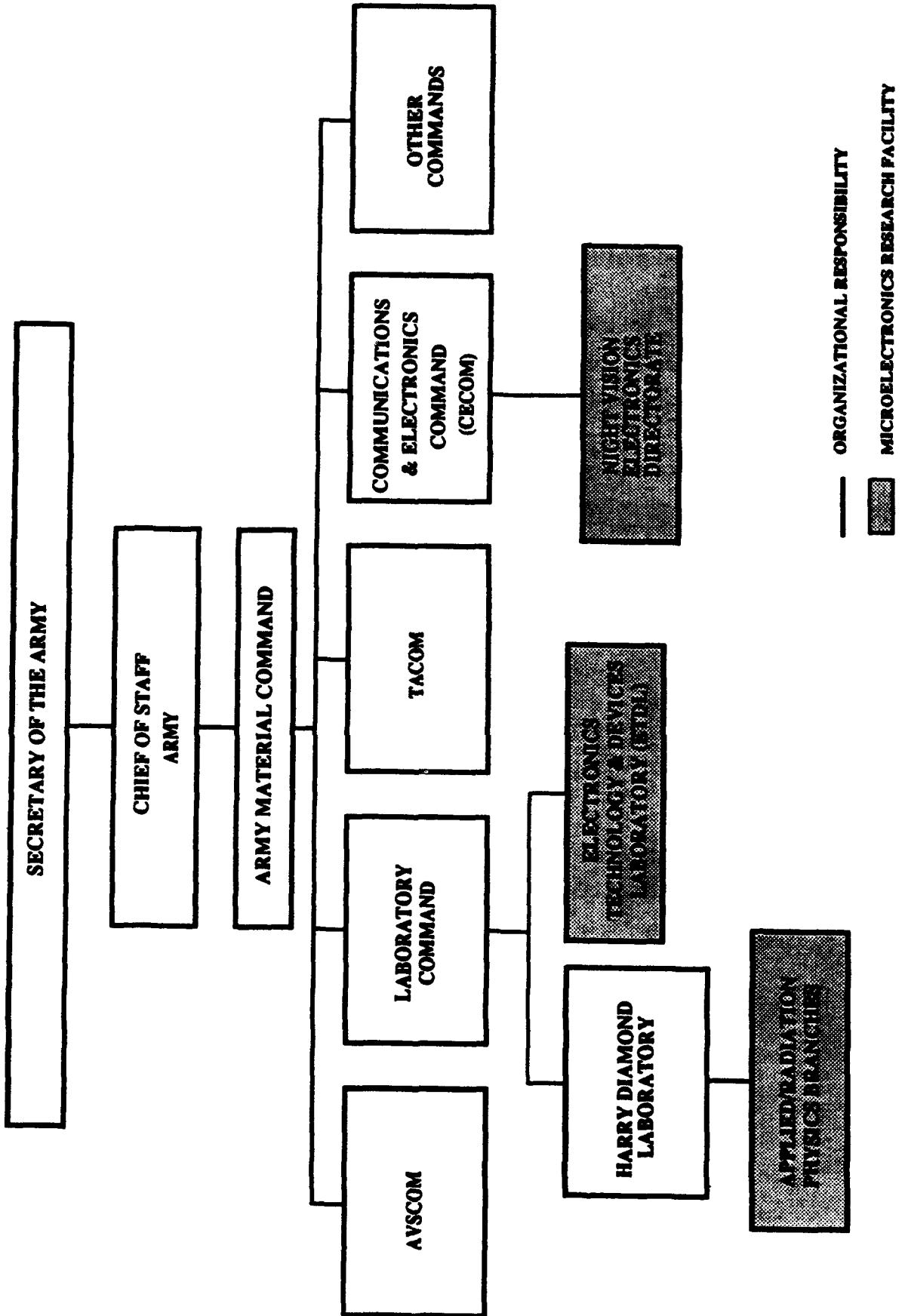


Figure C-1

MICROELECTRONICS FACILITY ORGANIZATIONAL STRUCTURE

-NAVY-

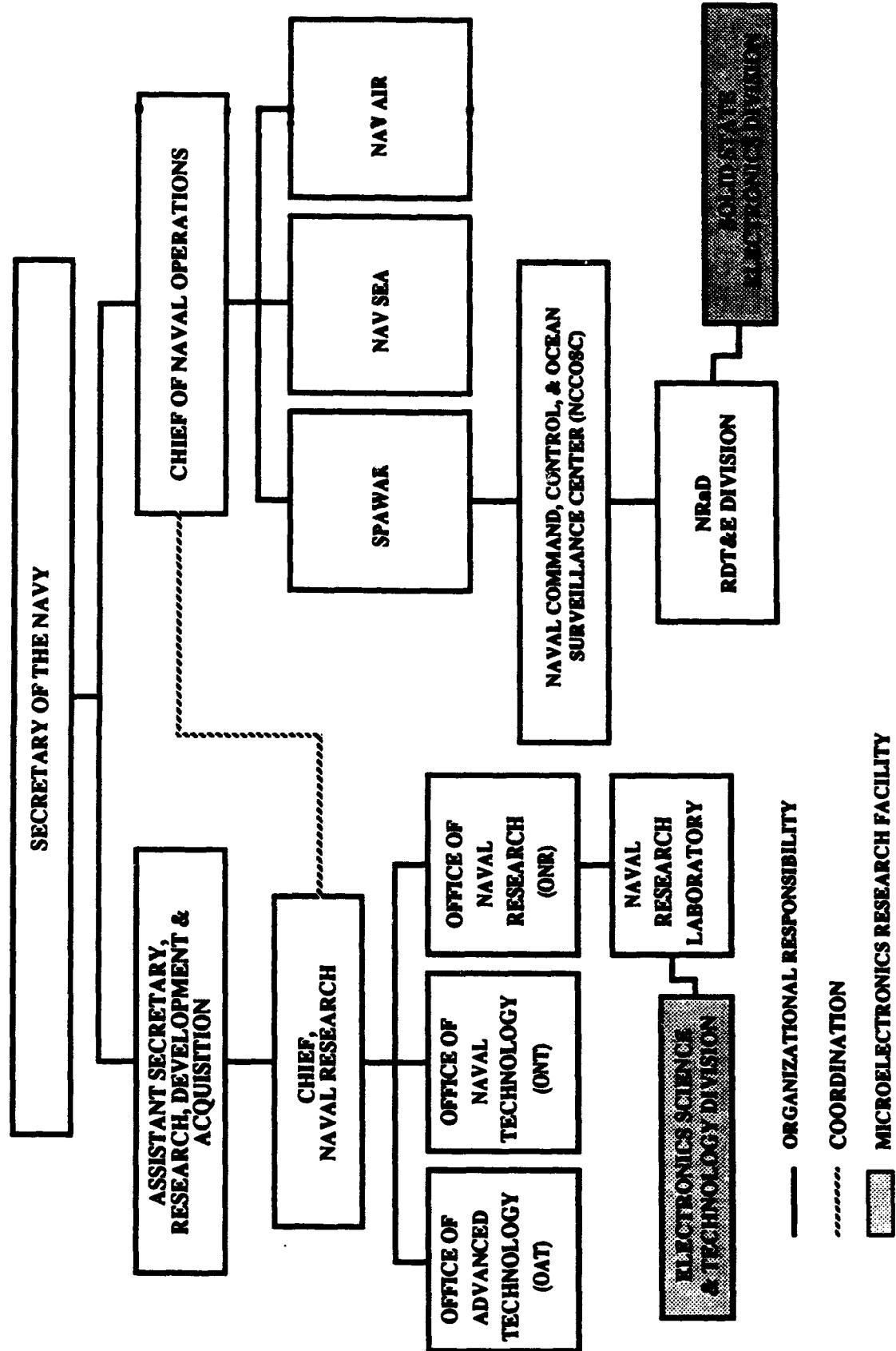


Figure C-2

MICROELECTRONICS FACILITY ORGANIZATIONAL STRUCTURE

- AIR FORCE -

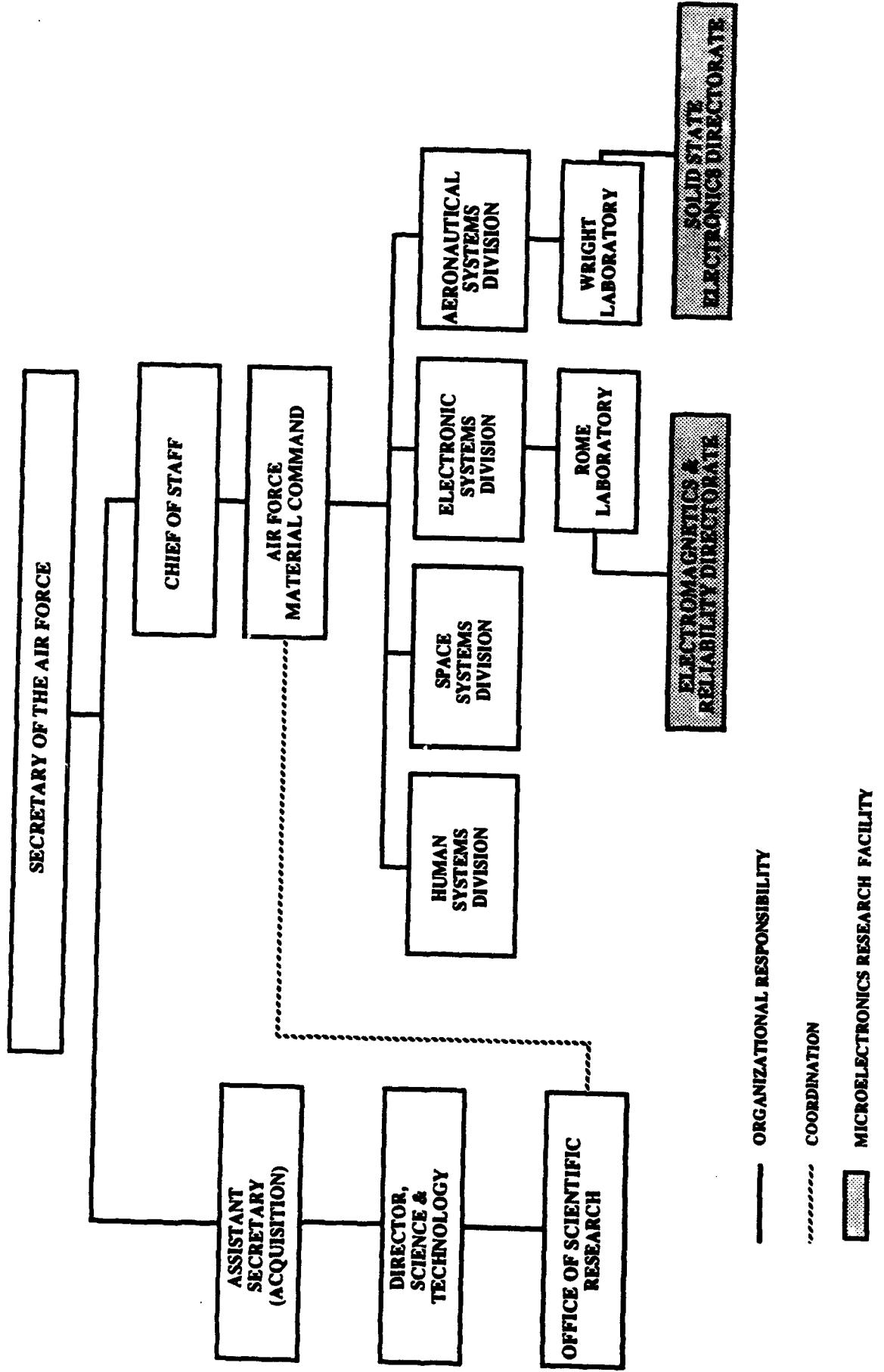


Figure C-3

ATTACHMENT 1

**HARRY DIAMOND LABORATORIES
ADELPHI, MD**

MISSION:

- Optoelectronics for sensors and signal processors
- Radiation-hardened semiconductor and electronic materials technology

TECHNICAL CAPABILITY:

- Growth and fabrication of research devices in III-V semiconductors
- Growth and fabrication of silicon and ferroelectric circuit elements for testing against nuclear radiation

TOTAL LAB SPACE: 8800 sq. ft.

CLEANROOM SPACE (Class 100 or better): none

STAFF: 18 total; 16 S&E

FUNDING:

Annual Funds (spent in-house): \$2.4M
Equipment Acquisition Cost: \$13M
1993 Planned Upgrade Cost: \$500K
External R&D Contracts: none
Sources: Army, DARPA, DNA, SDC, NASA, Navy

**ELECTRONICS TECHNOLOGY AND DEVICES LABORATORY
FORT MONMOUTH, NJ**

MISSION: To develop and transition new and enabling technology into Army systems through continuing joint development with R&D centers, laboratories, and project managers.

TECHNICAL CAPABILITY:

- ETDL's technical capabilities are identified by the following core competencies:
 - Nano/optoelectronic/photonic devices
 - Microwave/Millimeter/MIMIC devices (including tubes)
 - Optical devices and focal plane arrays
 - Advanced sensor/actuator devices
 - Design/simulation, modeling, concurrent engineering and prototyping
 - Reliability and manufacturing science
 - Acousto/ferroelectronics
 - Virtual environment (display) devices
 - Power sources (including pulse power)

TOTAL LAB SPACE: 44,500

CLEANROOM SPACE (Class 100 or better): 6,400 nsf

STAFF: 206 total; 175 S&E

FUNDING:

Annual Funds (spent in-house): \$83.5M

Equipment Acquisition Cost: \$40.8M

1993 Planned Upgrade Cost: \$2M (includes facilities upgrade)

External R&D Contracts: \$12.8M mission funded (est)

\$37.7M customer funded (est)

Sources: DARPA, RDECs, PEOs, MNs, Navy, AF, NASA

**NVEOD
FORT BELVOIR, VA**

MISSION: Research, development and producibility of advanced sensor materials, components & devices for application to Army/DoD reconnaissance, surveillance and target acquisition activities.

TECHNICAL CAPABILITY:

- Infrared materials growth, characterization and evaluation
- Laser materials growth, characterization and evaluation
- Infrared focal plan array/detector test and evaluation
- Laser diode array fabrication, test and evaluation
- High throughput miniaturized image processors
- Microelectronic modeling device performance
- Sensor sub-assembly test and evaluation
- IR/laser manufacturing technology for producibility

TOTAL LAB SPACE: 42,000 sq. ft.

CLEANROOM SPACE (Class 100 or better): 6,000 sq. ft.

SYSTEM APPLICATION:

- Forward Looking Infrared (FLIR) sensors, infrared search and track systems, missile seekers, laser rangefinders, designators, laser countermeasure systems, laser radar sensors

STAFF: 480 total; 313 S&E

FUNDING:

Annual Funds (spent in-house): \$26M

Equipment Acquisition Cost: \$21M

1993 Planned Upgrade Cost: \$2.6M

External R&D Contracts: \$17.2M

Sources: Mission RDT&E, DARPA

**ELECTRONICS SCIENCE AND TECHNOLOGY DIVISION
NAVAL RESEARCH LABORATORY
WASHINGTON, DC**

MISSION:

- Participate in the advancement of knowledge, understanding and technology of electronics by in-house research in materials, processes, devices and circuits
- Address unique or predominantly military needs both by in-house performance and by industrial interactions
- Develop new state-of-the-art devices and circuits with emphasis on performance, affordability and robustness
- Search out new Navy applications for emerging technologies
- Perform technology transfer to the private sector as appropriate

TECHNICAL CAPABILITY:

- Growth of semiconductor, dielectric, superconductor and metal materials
- Determination of electronic material and interface properties
- Processing science and technology of nano and microelectronic structures, devices, and circuits
- Solid state device and circuit design, fabrication, and experimentation
- Failure physics, radiation vulnerability and hardening of electronic components
- Vacuum electronics theory, component design, fabrication, and experimentation
- Complete fabrication capability of: silicon submicron CMOS, NMOS, CCD; GaAs FET, HEMT, HBT; silicon micromachining; and nanostructure devices and circuits

TOTAL LAB SPACE: 42,825 sq. ft.

CLEANROOM SPACE (Class 100 or better): 625 sq. ft.

SYSTEM APPLICATION: Space, EW, radar, communications, navigation and smart munitions

STAFF: 140 total; 125 S&E

FUNDING:

Annual Funds (spent in-house): \$39.4M
Equipment Acquisition Cost: \$23M
1993 Planned Upgrade Cost: \$471K
External R&D Contracts: \$16.5M (FY-92)
Sources: ONR, ONT, AF, ARMY, DNA, DARPA, SPAWAR, NAVAIR, NAVSEA

**SOLID STATE DIVISION
NCCOSC R&D DIVISION
SAN DIEGO, CA**

MISSION: Perform research and development, test, and evaluation of solid state electronic and optoelectronic materials, devices, and circuits for Navy applications with emphasis on silicon and III-V compound materials, including processing technology.

TECHNICAL CAPABILITY:

- Microelectronics processes include Complementary Metal on Semiconductor (CMOS/Silicon-on-Sapphire (SOS), 0.75 micron minimum feature size, and bulk silicon.
- Under development: bipolar in SOS, ohmic contact formation in III-V and diamond electronic materials, Metal Insulated Semiconductor Field Effect Transistor ((MISFET) fabrication, and monolithic PIN-FET fiber optic receivers.

TOTAL LAB SPACE: 32,154 sq. ft.

CLEANROOM SPACE (Class 100 or better): 5,500 sq. ft.

SYSTEM APPLICATION: Trident, Strategic Defense Initiative (SDI), satellite surveillance, guidance, and navigation

STAFF: 85 total; 66 S&E

FUNDING:

Annual Funds (spent in-house): \$11.5M

Equipment Acquisition Cost: \$22.6M

1993 Planned Upgrade Cost: \$380K

External R&D Contracts: \$3.1M

Sources: Naval Aviation Depot, NIPO, SSP, ONR, NRL, ETDL, DLA, DIA, DARPA, USASDC, DNA, AF

**WRIGHT LABORATORY
WRIGHT-PATTERSON AFB, OH**

MISSION: Direct and conduct contractual and in-house research to develop the technology base for advanced solid state electronics

TECHNICAL CAPABILITY:

- Microelectronics/microwave/ opto-electronic device design and fabrication
- MBE based device processing
- 0.1 um mushroom gate processing using EBL
- Microelectronics computer aided design facility
- MMIC baseline fabrication process for MESFET and HEMT
- Discrete device fabrication process for HBT, BFET, HGFET, and PHFET
- Discrete device fabrication process for opto-electronic devices
- High speed testing of microelectronic devices, circuits, and A/D's
- Microwave/millimeter wave device and circuit characterization

TOTAL LAB SPACE: 22,800 sq. ft.

CLEANROOM SPACE (Class 100 or better): 6,150 sq. ft.

SYSTEM APPLICATION:

- Fire Control
- Electronic Warfare
- Surveillance
- Communications
- Navigation
- Smart munitions

STAFF: 140 total; 100 S&E

FUNDING:

Annual Funds (spent in-house): \$6.8M

Equipment Acquisition Cost: \$37M

1993 Planned Upgrade Cost: \$1.75M (includes facilities upgrades)

External R&D Contracts: \$52M

Sources: AFOSR (Direct), SSE Mantech (Direct), LLIR (Direct), 6.2 (Direct), DARPA, SBIR

**ROME LABORATORY (RL)
LINCOLN, MA**

MISSION: Electronic/photonic device technology and supporting technology base R&D for C³I

TECHNICAL CAPABILITY:

- Optical/microwave device (including 2-D devices) design, computer modelling, and fabrication
- InP microwave device design/fabrication/testing to 120 GHz
- Si and SiGe guided wave devices
- InP/GaAs crystal growth and wafer technologies
- Metal-organic chemical vapor deposition (MOCVD) of III-V thin films and ultrastructures
- Low temperature CVD dielectric deposition
- High temperature superconductor film deposition (sputtering, metal-organic decomposition, laser deposition)
- Structural, electrical optical, and magnetic characterization of semiconductor materials and devices

TOTAL LAB SPACE: 15,200 sq. ft.

CLEANROOM SPACE (Class 100 or better): 100 sq. ft.

SYSTEM APPLICATION:

- Technology base and component development support for:
 - AF photonics program at RL
 - Technology transfer to industry
- Milsatcom terminals (T/R modules, antennas)
- Ground-based radar antenna array systems
- Optical communications systems

STAFF: 44 total; 32 S&E

FUNDING:

Annual Funds (spent in-house): \$5M

Equipment Acquisition Cost: \$19M

1993 Planned Upgrade Cost: \$2.5M (includes facilities upgrade)

External R&D Contracts: \$4.5M

Sources: AFMC, DARPA, AFOSR and ILIR

APPENDIX D

LABORATORY VISITS AND MEETINGS

APPENDIX D

LABORATORY VISITS AND MEETINGS

During its study, the Task Force visited most of the Army, Navy, and Air Force in-house laboratories which are engaged in significant microelectronics research and development. These included:

*Naval Research Laboratory, Washington, D.C.
NCCOSC (RDT&E Division), San Diego, CA
Wright Laboratory, Dayton, Ohio
Rome Laboratory, Bedford, MA
Army ETDL, Fort Monmouth, N.J.
Harry Diamond Laboratory, Adelphi, MD
Night Vision Laboratory, Ft. Belvoir, VA*

In addition, it visited Sandia, Lincoln Lab, and NSA since each of these Government-supported laboratories carries out significant Defense-related R&D in the areas of interest.

These laboratory visits were part of the fact finding process used by the Task Force. Each followed the same general format.

Typically, the format included an overview of the laboratory, its mission, organization, funding structure, areas of emphasis and method of operation, presentations by, and discussions with, the managers who provide technical leadership for the in-house and external efforts; visits to selected facilities within the laboratories and short exchanges with the technologists actually carrying on the R&D efforts. Often, there were opportunities to converse with customers.

In addition, there was opportunity to talk with key sponsors in each Service (ONR, ONT, ARO, AFOSR). The same format was followed for the visits to Sandia, Lincoln and NSA. Further, the Task Force was briefed by DARPA and DNA who are also part of the customer base for the laboratories' services.

The purpose behind the laboratory visits had several facets:

- To examine the "smart buyer" premise as the primary justification for in-house laboratory efforts.
- To learn how each activity serves and supports its primary and subordinate customer bases. Ultimately, the primary customer base is viewed as the U.S. war fighters. Microelectronics advances have broad, indirect impact on fighting forces through a set of tiered activities. These activities include equipment and systems oriented in-house and/or contractor efforts.
- To understand the mission and methods of operation for each group visited, and to assess the effectiveness of the processes employed.
- To find the degree to which Service facilities are connected to the Defense industry and other outside (or inside) related R&D efforts.

- To understand the funding processes used to support the various activities implied by the missions.
- To examine the quality of the staff, the appropriateness of the physical plant and associated equipment, and the general productivity of the R&D effort.
- To learn the extent and effectiveness of synergistic interactions with other related technologies such as materials, physics, and chemistry.
- To understand how priorities are established and to gain an appreciation of how efforts to support the seven DoD thrusts are effected within established missions.
- To examine the process and quality of technology and product transition from the laboratory to military systems and to industry.
- To assess the effectiveness of various R&D coordinating efforts among in-house and contractor programs.

The results of the visits confirmed impressions gained during the Laboratory Commanders' presentations that there is commonality of purpose. However, distinct differences in philosophy and execution among the three Services emerged.

The Task Force gained insight into how the various R&D systems operated in the 6.1, 6.2, and 6.3A areas. This was possible in the short time available because of the openness and responsiveness of the laboratories' leadership.

We found the quality of the technical staff to be very good, certainly better than was the case five or ten years ago. For example, ETDL at Fort Monmouth has been successful in recruiting several excellent researchers from AT&T Bell Labs and focusing their efforts on Army mission problems. All of the labs could benefit by improved understanding of Service applications. This understanding would enhance their ability to talk to their customers and their customers' contractors.

Besides the quality of the staff, the Task Force found the work being done to be quite good although the current relevance and/or emphasis of some projects might be questioned. Clearly there are differences among the labs, but the Task Force felt the extent of the differences observed did not warrant special comment.

The seven areas of technology thrust which have been identified as critical for future Defense efforts are well covered and are integral to the strategic planning of the in-house Service laboratories. Microelectronics, of course, plays a key role in all seven areas.

On average, the laboratory facilities were excellent including equipment for material processing, analysis, and testing devices and circuits. The Task Force recognizes the value of MBE (molecular beam epitaxy) machines for the precise control of material growth virtually to the level of atomic layers. It also recognizes that the number of machines required is dependent on the specific materials being processed. However, the expensive cost of these machines and the decreasing budget require that a mechanism be established for coordinating the acquisition of such equipment among the Services. There are often ways to gain access to MBE equipment or to the product of

MBE systems without the financial burden of ownership. There are companies that will tailor-make MBE material in response to a specification. While MBE equipment has been singled out for comment, the same can be said of other microelectronics equipment within the DoD laboratory complex.

The Task Force gained the impression that the Services tend to exhibit an optimistic view of what facilities cost (initial purchase, maintenance/upgrade, and operating). They also tend to be aggressive in terms of what facilities are really needed to accomplish a set of R&D tasks.

Because of the accounting processes used (which appeared to vary from lab to lab), the Task Force found it difficult to approach lab cost issues in a way that is similar to industry. There is no way of measuring ROI, and it is very hard to identify the real cost drivers. One can argue that fewer people mean less cost across the board, which is the current DoD method. This may be too simplistic and misleading because it neglects the value of output. However, since output of an R&D facility is hard to quantify in financial terms, containment or curtailment of staff may be the only means of control for a Government lab.

The balance between in-house efforts and external contracts varies from Service to Service and lab to lab. As a guideline, the Task Force feels there should be a reasonable balance between internal and external programs in the 6.1 area with an increasing outside emphasis in the 6.2 (perhaps 70%) and 6.3A (more than 90%) areas. The microelectronics group at Wright Laboratory apparently follows a policy of in-house versus external contracts that tends to favor outside efforts. It was stated that they could handle an additional \$50-100M in external contract funds without an increase in staff. It was also indicated that internal 6.1 funding from the AFOSR (80% of Wright Lab total 6.1 funding) was provided on merit on a task by task basis. The Task Force believes this approach to be a good one but has the impression that the funding process may not be the same in the other laboratories.

It became apparent to the Task Force that a sizable portion of the effort underway in the various microelectronics research laboratories was focused on research issues that were common across the Services. In other words, the question of Service uniqueness is "fuzzy". While not necessarily redundant, the nature of some research carried out at each of the laboratories visited was as applicable to the needs of one Service as it was to either of the other two. Hence, some consolidation could be accomplished or leverage gained on those research efforts which were aimed at the 6.1 segment of the R&D spectrum. Such rationalization could be accomplished as the Reliance effort becomes more effective.

As anticipated, we found very little effort underway on conventional silicon-based microelectronics (save for radiation hardening, microelectronics manufacturing science and technology-MMST, and some aspects of packaging) at the Service laboratories. The effort at all labs was much more concerned with issues of advanced technology such as compound semiconductor materials phenomena, related devices, and their application to microwave, millimeter wave, and photonic requirements. Additionally there were a variety of efforts focused on high temperature superconductor materials and devices and semiconductor devices that could operate at elevated temperatures (>200°C).

The first class principal facilities at Sandia National Laboratory in Albuquerque, New Mexico, and the NSA Special Processing Laboratory (SPL) at Ft. Meade, Maryland, are geared more toward production of silicon integrated circuits than research. As in industry, production means the fabrication of hundreds, even thousands, of wafers a year using stable, tightly controlled, and repeatable manufacturing processes. These production facilities were each designed to support requirements of their respective missions. In the case of NSA, the issue of security is the determining factor with respect to in-house or external manufacture. For Sandia, the focus was support of the nuclear weapons systems efforts. Sandia has a great deal of excess capacity as a result of changing priorities.

Sandia and NSA are interesting case studies of the use of contractors. NSA/SPL is a Government-operated facility with a major support contractor, National Semiconductor, which provides operating support and new processes. The intent is to provide timely access to commercial production technology as it is brought on line in the commercial sector. Sandia is a Contractor-operated (GOCO) facility--all employees are contractors. The contractor is AT&T which operates both Defense and commercial facilities.

In addition to the production facilities, both NSA and Sandia operate research facilities. NSA's smaller laboratory, called the Microelectronics Research Laboratory (MRL), is located in Columbia, Maryland. In contrast to production, research efforts might entail processing as few as one or two wafers at a time using varied procedures to achieve a specific result, or demonstrating the viability of a given process (like metallization, ion implantation), or proving out a circuit design. MRL has been designed not only to pursue research efforts but also as a production back-up (internal second source) in the event of a catastrophe (fire, etc.) in the principal facility (SPL). Sandia is doing research in both silicon and III-V compound devices; NSA, at this point, is involved only in silicon.

Both Sandia and NSA are seeking additional customers to support their production facilities.

Without exception, every laboratory was aligned to the "smart buyer" concept, recognizing that they could be effective only if coupled closely to the user community. Some laboratories appeared to be more aggressive and disciplined in supporting their system counterparts and the industrial infrastructure which supports the systems acquisition process (OEM's). Both Lincoln Lab and Sandia were found to be tightly coupled within the framework of their overall missions. Their respective organization structures are conducive to a tight coupling because of the commonality of authority -- both functions report to the same boss. The same is true of the Night Vision Laboratory and NSA.

It is very important to recognize that the researcher-user link exists throughout the life cycle of a specific system or piece of equipment, although the connection takes on different characteristics as a function of time. For example, at the system concept stage, even before anything is designed, this linkage is very important because it affords the user (the "smart buyer" of systems) access to accurate and objective trade-off analyses between competing device technologies as well as a view of future developments. This kind of study is as important from a cost point of view as it is in terms of performance. At the other end of the spectrum, one finds, increasingly, a dilemma with mature fielded systems for which spare parts cannot be purchased because industry has stopped their manufacture (often for economic reasons or because the technology used for their manufacture has become obsolete). In these cases, which become increasingly vexing in the microelectronics area, the users absolutely need the support of competent in-house device experts who can either solve the problem directly or lead industry to a mutually satisfactory solution.

The in-house staff of a microelectronics research facility should be regarded as "experts" in their areas of specialization and advocates for its application. They should serve as a resource for the in-house systems personnel as well as their systems contractors.

The Task Force encountered numerous examples of new technology insertion as well as the solution of critical problems related to new and existing Defense systems each of which strongly validates the "smart buyer". For example :

- Efforts at the Army's ETDL solved a major failure problem in the travelling wave tubes (TWT) used in the TPQ-36 and 37 transmitter. Tube life was only 100 hours due to the failure of the cathodes in the TWT's. There was only one source of supply available and the tube cost was \$60,000 each for the TPQ-36 and \$125,000 each for the TPQ-37. ETDL personnel analyzed the failure mechanisms, developed a solution, pursued a competitive bid, and now have two sources for the TWT's costing \$20,000 for the TPQ-36 system and \$60,000 for the TPQ-37. This represents a 66% reduction in cost for the TPQ-36 tube and a greater than 50% reduction in cost for the TPQ-37 TWT. These significant savings in cost were achieved in addition to a greater than order of magnitude increase in operating life to in excess of 3,000 hours. This is a classic example of in-house technology impacting "smart buying" well into the logistics cycle. Insertion of this technology will result in system life cycle cost savings well in excess of \$200M.
- In another case, Harry Diamond Lab (HDL) in collaboration with ETDL, developed a Multi-Option Fuze Artillery (MOFA) which eliminated the need for seven different fuzes in the Army inventory. Moreover, the fuze system uses a Doppler radar fuze which is more secure than those previously used. The heart of this new system, now in full-scale development, is a microwave monolithic gallium arsenide integrated circuit (MMIC) chip in which a complete 100 milliwatt FM CW homodyne radar is embedded. This is an insertion example of the newest technology which is enabling a new class of fuze for artillery and mortar applications.
- In still another case, HDL laboratory personnel played a major role in fuze design for the upgraded Patriot missile so the system could be employed against aircraft as well as tactical ballistic missiles (TBM). The fuze is a pulse Doppler radar system whose task is to determine the proximity of the target and time the detonation of the Patriot warhead to maximize its lethality. HDL personnel increased the system sensitivity to detect smaller radar cross-section, added a second, more forward looking antenna to allow earlier detection of a high speed TBM, and modified signal processing algorithms to reduce processing delays. The fuzes were utilized in the Saudi Arabia theater and in Israel.
- A telling example of how the "smart buyer" can solve a field problem relates to the difficulties encountered in helicopters flying over featureless terrain (sand dunes in Desert Storm) in which pilots were unable to see the sand dunes and hence crashed into the dunes. This problem, brought to the Night Vision Laboratory (NVL), was solved by Night Vision technical personnel who identified and adapted an existing technology (laser diode aiming lights) which when incorporated in a strut system and attached to the helicopters, enabled the pilots to avoid collision with sand dunes. NVL built in-house and delivered several hundred systems to Saudi Arabia which were used in actual sorties. This kind of in-house laboratory contribution represents a demonstration of core competence, "corporate memory", ability to innovate and adapt technologies to solve real world problems in real time.

- Infra-red focal plane array (IR-FPA) technology is critical to certain classes of missile seekers. The JAVELIN system (an anti-tank weapon system) depends on a fire and forget missile that is guided to its target by an IR-FPA seeker. The system contractor opted to develop an IR-FPA based upon metal-insulator-semiconductor (MIS) photocapacitor technology which places very stringent demands on the semiconductor material. After fabricating several thousand FPA's without success, the approach was abandoned thus jeopardizing the entire JAVELIN system.

Night Vision Laboratory personnel, as a result of in-house theoretical and experimental efforts, demonstrated the feasibility of IR-FPA's for this kind of application using photodiode (instead of photocapacitor) arrays and successfully led two contractors to the development of satisfactory photodiode IR-FPA's. This effort allowed the JAVELIN system to proceed as planned, and provides a good example of in-house core competence and the ability to provide leadership to industry.

- In response to an unanticipated maintenance problem with the F-15 and F-16 LANTIRN system during Desert Storm Operations, Wright Laboratory personnel were called on to solve a diagnostics problem with the navigation pod window. The outside of the pod window essentially was sand blasted as result of high speed, low altitude flight in the desert environment, thus rendering the system inaccurate. There was no built-in-test system or convenient way of determining the degree of window degradation short of dropping the pods and performing a full systems test. This was time consuming and limited the availability of these aircraft for combat missions.

Based upon their extensive experience with infrared transmission and scattering phenomena, Wright Laboratory engineers developed a method for calibrating window quality by correlating surface scattering with the infrared transmission properties of the window. These findings formed the basis for contractor developed portable scatterometers which could determine the degree of window degradation in a matter of minutes without removing the pods and suffering unnecessary system down time.

While the foregoing is an example of technology adaptation to solve an Air Force operational problem with systems already in the field, the following is representative of technology insertion during the very early phases of systems development.

- Wright Laboratory engineers have become very proficient in the software system known as VHSIC Hardware Description Language (VHDL). By evaluating the way this new and revolutionary scheme for describing and simulating systems, circuits, and components is used for internal needs and the way VHDL has been written and used by others across the industry, Wright Laboratory personnel have acquired significant expertise which has enabled them to make substantial contributions to the development of VHDL related military standards, Federal Information Processing Standards, industry standards, the data item description, upcoming new DoD acquisition policies, and VHDL model validation procedures.

Wright Labs developed in-house a set of over 200 benchmarks and stress tests for VHDL simulation systems. These tests have allowed major weapon system contractors to evaluate the quality of VHDL systems before they procure them.

Wright Labs supported the Joint Integrated Avionics Working Group (JIAWG) for the Advanced Tactical Fighter (now F-22), by providing network access and engineering support to a VHDL simulator.

Wright Labs is currently evaluating VHDL simulation systems for the F-22's Gate Level System Simulation initiative.

The financial leverage in terms of cost savings which VHDL is expected to provide will be measured in billions of dollars.

A new initiative aimed at creating a hardware description language for microwave/millimeter-wave monolithic integrated circuits (MIMIC) has been launched under DARPA sponsorship. This effort, called MHDL (MIMIC HDL), like VHDL, is a coordinated Tri-Service program with a leadership role assigned, via Reliance, to ETDL. While VHDL focusses on digital IC's, MHDL is directed toward analog functions.

There are times when laboratory personnel are brought in to help solve production problems. These may occur when a device design exhibits performance feasibility but cannot be successfully transitioned into production (the case for the focal plane array mentioned earlier) or when a device is being manufactured but proves to be unreliable and requires redesign (the case of the TPQ-36, 37 TWT's). A third example occurs when a manufacturing process goes out of control causing very poor yields and both low output and unreliable production parts.

- As an illustration of the latter, NCCOSC (NRaD) was called on to help solve a severe yield problem for the star sensor used in the guidance system of the Trident D5. The prime contractor was having difficulty achieving yield on the charge-coupled device (CCD) detector used in the guidance system. The NRaD microelectronics facility took the existing design, simulated, and duplicated the process in-house. Then NRaD's chief process engineer personally spent eight months at the contractor's facility, consulting and, in many instances, personally supervising the contractor's fabrication line until success was achieved in obtaining satisfactory yields of CCD detectors. Following this success, NRaD's chief process engineer assisted in the establishment of a second fabrication source with another vendor. In both instances, the ability to duplicate processes in-house, coupled with state-of-the-art processing equipment and in-house technical expertise enabled the Navy to overcome procurement problems for a major strategic weapons system.
- Another important function of in-house laboratories is to be an advocate for particular areas of electronics that may no longer be in vogue but for which there are opportunities that additional R&D could impact a clear military need. An example of such an area is vacuum electronics and more specifically its application to high power RF amplification and generation. In spite of all the advances of solid state RF device technology, there remains a large parametric frequency-power regime which can only be satisfied by vacuum electronic components. As a result, the final output stage of many RF systems in the military inventory uses a power tube. A prime example of power tubes as an enabling technology is the Navy's AEGIS SPY-1 radar. In the future, new RF systems needed to respond to new threats or give new capability will also require performance characteristics attainable only by novel vacuum electronic components. Yet over the last ten to fifteen years the amount of R&D funding going into this area has been steadily eroding. This lack of support has blunted the industry's ability to respond to these future Defense needs. The Naval Research Laboratory has been a singular and consistent voice for action to stimulate the vacuum electronics R&D community. As a result of their advocacy, the DoD Advisory Group on Electronic Devices (AGED)

performed a special technology review. They concluded that indeed a timely infusion of new R&D support was crucial to the DoD and issued a report entitled "Microwave Power Tubes: A National Security Concern". This report served as a catalyst for Navy, DoD, and Congressional action resulting in a major initiative to revitalize the military R&D vacuum electronics community.

- The first GaAs high electron mobility transistor (HEMT) reliability study was performed by the Naval Research Laboratory. HEMT's have been found to have the lowest noise figure for front-end receiver applications in satellites and other Navy systems. Failure mechanisms were revealed by this study that were not suspected at the time and the predicted life times for the HEMT's were found to be only 10,000 hours. When this study was reported in the literature in 1985, there was skepticism expressed in some quarters, but when companies repeated similar studies on their HEMT's, similar results were found, including the failure mechanisms of two-dimensional electron gas (2 DEG) deconfinement, gate inter-diffusion into the AlGaAs layer, and ohmic contact degradation. Improvements were then immediately developed and more reliable HEMT's fabricated by the companies, thus enabling the early insertion of this leading edge technology into Navy and other Defense systems. This is another example of industry leadership by in-house Defense laboratories.
- For many years, NRL has been recognized internationally for its work on radiation hardening techniques for MOS structures and, in fact, developed a hardening process and transferred the process to industry (RCA and National Semiconductor). The resulting radiation hard circuits were used in various satellites (TIRDS, DMSP) and space probes (such as Voyager).

At very high levels of integration (LSI, VLSI), the problem becomes even more challenging because the field oxide requires hardening. Suitable techniques were developed at NRL and transitioned to the RICMOS process at Honeywell. Products derived from this hardened RICMOS process are found in many Defense systems such as Trident, GPS, MILSTAR, and DSP. NRL is continuing their leadership role to provide hardening processes for 1 M-bit SRAMS built on SIMOX. Currently, NRL is supporting DNA/SDI sponsored efforts at TI, Honeywell, and IBIS.

The foregoing series of "bullets", reflecting a few examples of how in-house laboratory efforts impact the Defense logistics system, has been included in this Appendix for several reasons:

- 1 - They provide graphic support of the "smart buyer" concept;
- 2 - They illustrate various ways in which this support is manifest;
- 3 - They demonstrate that in-house laboratory personnel are directly involved from the beginning of system development to its removal from the Defense inventory -- a life cycle involvement. Moreover, it is not difficult to infer that had early involvement been the rule, the need for "diving catch" solutions would have been less.
- 4 - The Task Force has been very impressed with the degree to which in-house laboratory personnel have contributed directly to the solution of major problems.

Support of the user community is not a one-way street. The user community must want and reach out for the support. This is a major problem as may be deduced from the foregoing remarks.

The user connection, perhaps the most important attribute of a successful MRF, is central to the "smart buyer" strategy. Relationships among personnel from the MRF and user groups at the R&D and engineering working levels which encourage and facilitate on-going lateral communications are essential for success. Dependence on conventional pyramidal communication channels severely blunts the efficient two-way flow of technical applications information. Hence, comingling of MRF and user personnel is key to an effective execution of the "smart buyer" function. Comingling can be effected by various management techniques including joint R&D projects, creation of "tiger teams" to address critical problems, and bilateral rotational and temporary duty assignments between user and the laboratory communities.

The Air Force appeared to be very aggressive and proactive in their approach to the R&D planning process which includes feedback from the user community. The Task Force felt it represented a good model in this regard.

It should also be noted that the emphasis on research will vary depending upon the evolution of the technologies. Properly, for example, little effort is focused on conventional silicon microelectronics because of its maturity and the fact that industry is driving the technology. Nevertheless, it is important for in-house laboratory personnel to be aware of what is happening and be able to provide guidance to the users in terms of exploitation. However, for the most part, the need for in-house research in this area has dissipated. On the other hand the in-house effort on microwaves and photonics is appropriate because these are still emerging technologies which promise to have major impact on future Defense systems. Interestingly, there exists an R&D renaissance in microwave tubes, a technology that has been neglected in recent years, and the laboratories correctly are providing leadership in this area.

During the visitation process and in subsequent Task Force discussions, the Reliance process was repeatedly raised as the key methodology for interservice coordination. The Task Force believes that Reliance is a good start but that its charter must be expanded to include coordination of equipment and facilities as well as programs. We are convinced that successful consolidation without loss of effectiveness requires a stronger Reliance or Reliance-like effort.

APPENDIX E

SCENARIOS

APPENDIX E

SCENARIOS

1. Single DoD Microelectronics Research Facility -- Government Operated.

A single, central DoD microelectronics research facility serving all of DoD. The facility could be operated by a lead Service, a Tri-Service entity, or by OSD.

2. Single DoD Microelectronics Research Facility -- Contractor Operated.

A Government-Owned, Contractor-Operated microelectronics research facility serving all of DoD.

3. Three Service Microelectronics Research Facilities.

Each Service would have only one microelectronics research facility which would serve the needs of the entire Service community. The major body of microelectronics staff at these facilities would perform, or contract for, microelectronics research spanning 6.1 - 6.3A. S&E's with microelectronics expertise may be distributed through other RDEC's, Warfare Centers, or Product Divisions, but they would not have substantial facilities.

4. Microelectronics Research Facilities Associated with Product Divisions.

Each Service would have only one microelectronics research facility closely associated with the product development, logistics and user communities. This facility would serve the needs of the entire Service community. The major body of microelectronics staff at these facilities would perform, or contract for, applications oriented microelectronics research and development, focusing most heavily on 6.2 - 6.4 work. S&E's with microelectronics expertise may be distributed through other RDEC's, Warfare Centers, or Product Divisions, but they would not have substantial facilities.

5. Single DoD Microelectronics Research Facility Plus Dedicated Service Applications Microelectronics Research Facilities.

A corporate microelectronics research facility serves the needs of all three Services, focusing primarily on microelectronics research having broad application. The spectrum of work is 6.1 - 6.3A, with the emphasis on 6.1 - 6.2. In addition, each Service would have one applications microelectronics research facility closely associated with the product development, logistics and user communities. This facility would serve the needs of the entire Service community. The major body of microelectronics staff at these facilities would perform, or contract for, applications oriented microelectronics research and development, focusing most heavily on 6.2 - 6.4 work with some 6.1 work. S&E's with microelectronics expertise may be distributed through other RDEC's, Warfare Centers, or Product Divisions, but they would not have substantial facilities.

6. **One Research Microelectronics Research Facility and Applied Microelectronics Research Facilities in Each Service.**

Combination in each Service of:

- 1) a research microelectronics research facility
- 2) applied microelectronics research facilities at RDEC's/Warfare Centers/Product Divisions

7. **Distributed Service Microelectronics Research Facilities Coordinated by Tri-Services**

Strong Tri-Service coordination of distributed microelectronics research facility organizations, i.e., each Service does its own thing - but strongly rationalized.

8. **No DoD Microelectronics Research Facilities.**

DoD gets out of the microelectronics research facility business and relies on private microelectronics R&D.

APPENDIX F

MANAGEMENT OPTIONS FOR A CORPORATE MICROELECTRONICS RESEARCH FACILITY

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MANAGEMENT OPTIONS FOR A CORPORATE MICROELECTRONICS RESEARCH FACILITY

1. NRL, Run as a Navy Organization

The NRL Electronics Division has the culture, history and existing capabilities to serve as the DoD corporate microelectronics research facility. Under this option, the responsibility for managing it would be assigned to the Navy to be administered by the Director of NRL, as it is run now, leaving it to him to consult with other Services, as he sees fit, to determine the technical program. The facility would remain at the NRL site. NRL would continue to be funded as now, mostly with Navy resources with transferred funds to address problems of the other Services at their option. Assignees from the other Services would be welcome to work in the NRL facility, subject to NRL management. The Tri-Service Reliance process would continue to operate collegially.

2. NRL, Run by Navy, with Tri-Service Oversight

Identical to Option 1, except that the technical program would be overseen by a Board of Directors appointed by the Service Acquisition Executives and DDR&E. The Tri-Service Reliance process could be formally tied into the corporate microelectronics research facility through this Board. Besides the Service representatives, the Board may include members from other DoD technical organizations such as DARPA, DNA, and NSA. Funding would consist of 20% from OSD, the remainder to be provided by the Services and Defense Agencies.

3. Commandeer NRL Facilities; Appoint Director Responsible to OSD

This option would remove the corporate microelectronics research facility from Navy management, making it responsible to OSD. The facilities would be those currently occupied by the NRL microelectronics operation. Program guidance would come from a Board of Directors appointed by the Service Acquisition Executives and the DDR&E and could include members from other DoD technical organizations such as DARPA, DNA and NSA. The Tri-Service Reliance process could be tied into the DoD corporate microelectronics research facility though this Board. Funding would consist of 20% from OSD, the remainder to be provided by the Services and Defense Agencies.

4. A Non-collocated DoD Corporate Microelectronics Research Facility

A DDR&E-appointed Director, responsible to OSD, would manage separate corporate microelectronics research facility elements, each at an existing Service site. The Director would receive guidance from a Board of Directors as indicated above tied into the Tri-Service Reliance process. The host Service would be responsible for most of the funding at that site, but additional funds would come from OSD and Defense Agencies.

5. Service Corporate Microelectronics Research Facilities at Service Option

NRL would continue as the Navy corporate microelectronics research facility, and the Army could establish a modest microelectronics research facility at Adelphi. The Air Force would continue its current system of combined research and application facilities at its option. No central direction except through the Tri-Service Reliance process.

APPENDIX G

COST PROJECTIONS FOR A MICROELECTRONICS RESEARCH FACILITY

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COST PROJECTIONS FOR A MICROELECTRONICS RESEARCH FACILITY

Based on the defined mission for the microelectronics facility to do advanced work in photonics, microwave devices, and advanced materials research primarily in compound semiconductors and heterostructures, the Task Force estimated, based on its industrial experience, that an adequate facility would have 10,000 square feet of clean space and laboratory space and office space for a team of 220 people. This sizing was estimated from analyzing the approximate equipment set that would be required by a commercial facility with a similar mission. This equipment set costs about \$50M. It was assumed that most of conventional silicon technology required by the Government would be acquired from commercial industry.

The Task Force used data from commercial microelectronics research facilities to construct a model of a "typical" facility. It is important to emphasize that the size and makeup of a particular facility may vary somewhat from this model depending upon the specific nature of the research conducted and equipment required and with different practices between industry and Government. For instance, a corporate microelectronics research facility might require less clean space and have a higher ratio of researchers and managers to technicians and operators as a reflection of the more basic nature of its efforts than facilities closer to applications activities.

Figures for the Task Force model are given in Table G-1. The acquisition costs were used to calculate the typical recurring cost of maintaining such a facility. The cost of a new building and facilities, e.g., air handling, heat, DI water, chemical storage, gas piping, and waste handling and/or treatment, with the characteristics specified is estimated to be about \$26.5M, approximately 40% of which would be the cost of facilities.

The staffing mix is heavily weighted toward scientists and technologists which accounts for approximately 50% of the work force. The other 50% is composed of technicians to support the scientists and maintain the equipment and operators who physically operate the equipment and run the facility. This mix is predicated upon the high degree of research and technical content that would be expected from a similar facility in the commercial sector.

Engineering overhead, i.e., the cost of materials, chemicals/gases, equipment and software maintenance, and power, depends on both the size of the facility and the number of people using it. Generally, in a commercial research facility staffed comparable to size, this runs 50% of technical personnel costs. The facilities and building replacement rates in the model are typical for commercial microelectronics research facilities. The microelectronics research equipment replacement rate is projected to be 20%. The rate is based on typical commercial microelectronics research equipment investments and is higher than for other laboratory equipment because the rate of change of microelectronics research is very rapid. The Task Force believes that a first class Government facility should use equipment comparable in generation to industry to facilitate an exchange of information and the capability to work together.

COST MODEL

Non-recurring Costs			
Bldg. & Facilities:			
	quantity ft ²	rate \$/ft ²	total (\$M)
Clean room space	10,000	2,200	22.000
Lab space	10,000	230	2.300
<u>Office space</u>	22,000	100	<u>2.200</u>
Subtotal			26.500
Research equipment			50.000
Recurring Costs			
Staff:			
	number	annual (\$K)	total (\$M)
Managers & technologists	105	57.14	6.000
Technicians	80	30.00	2.400
<u>Operators</u>	35	20.00	<u>.700</u>
Subtotal			9.100
Fringe	10.90%		.992
SS Taxes	6.70%		.610
Total labor cost			10.702
Non-recurring Cost Summary:			
Building			26.500
Equipment			50.000
Total non-recurring cost			76.500
Recurring Cost Summary:			
Staff (total labor cost)			10.702
Operating overhead- Building capital ¹	10.60	4.00%	.424
Facilities capital ¹	15.90	10.00%	1.590
Equipment capital		20.00%	10.000
Engineering overhead ²		50.00%	<u>5.351</u>
Total recurring			28.066

¹ 60% / 40% of total building and facilities

² Includes materials, chemicals/gases, maintenance, power, etc. -- normal administrative overhead not included

TABLE G-1

A Case Study

The cost of capital equipment necessary for a microelectronics facility is increasing at an annual rate of 15%, much in excess of inflation. As critical dimensions decrease and the requirements for higher purity materials increase, this trend will continue. In addition, while the geometric dimensions of the devices are getting smaller, the drive toward increased levels of integration and increased functionality will require ultra clean environments both in the physical facility itself and within the confines of the processing equipment.

The increase in equipment costs is illustrated in Figures G-1 and G-2 where the costs of fabrication equipment are plotted as a function of time for the growth of III-V and II-VI compounds and for lithography.

To create state-of-the-art devices in photonic technologies (i.e., laser diodes, modulators, detectors, and focal plane arrays) and in microwave technologies (i.e., monolithic microwave integrated circuits (MMIC), heterojunction bipolar transistors (HBT), and high electron mobility transistors (HEMT)) requires the growth of ultra thin, high purity, and carefully composited layers of semiconductors such as GaAs, InP, and HgCdTe. In the 1970's these layers were grown by liquid phase epitaxy (grown from a Ga solution) and vapor phase epitaxy (grown from GaCl and AsH₃ vapors) and achieved thicknesses of 1000 angstroms in systems that were generally homemade and cost anywhere between \$20,000 to \$100,000. In the 1980s, quantum electronics required controlled layers down to 10 angstroms thick which were grown in either molecular beam epitaxial reactors (ultra-high vacuum chambers using beams of atoms evaporating from heated metal sources) or metalorganic vapor deposition reactors (grown from metalorganic gases on a radio frequency heated substrate). These systems escalated in cost to an average of \$700,000 due to increased technical sophistication, as well as the necessity to meet more stringent safety and environmental requirements.

The newest growth technique, which is capable of depositing ultra pure and highly controlled monolayers, is MOMBE (a combination of metal organic and molecular beam epitaxy). The price of MOME growth equipment ranges from \$500,000 to \$2,000,000 depending on the optional capabilities and results in improved quantum photonic and microwave devices.

With all highly complex semiconductor processing equipment, the cost of maintaining and providing the necessary supplies such as starting material, chemicals and gases must be considered. Historically, this cost has scaled with the purchase price and remains about 20% of the initial systems cost on a yearly basis.

As shown in Figure G-1, over the past 20 years, the cost of tools to create highly complex structures for the state-of-the-art devices has increased by a factor of 20X, while during this same period inflation has increased only by a factor of less than 4X.

COST OF CRYSTAL GROWTH SYSTEMS

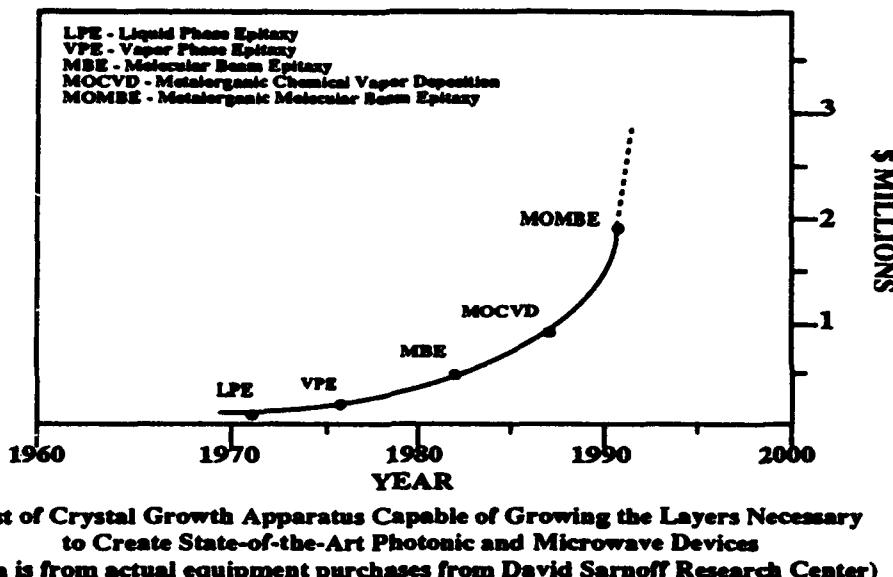


Figure G-1

Just as in producing ultra thin layered devices, lithography for state-of-the-art photonic, microwave and integrated circuits has progressed from five micrometers in the 1970's to two-tenths of a micrometer for experimental devices in 1992. This scaling of dimensions has driven the necessity to have lithography tools that have the resolution and registration tolerances required to print these complex structures. Improvements in lenses, use of different energy sources, and the addition of sophisticated systems for accurate stage placements have resulted in substantial cost increases as shown in Figure G-2. It is anticipated that this trend will continue as the complexity of new devices continues to increase and the critical dimensions to shrink.

COST OF WAFER EXPOSURE TOOLS

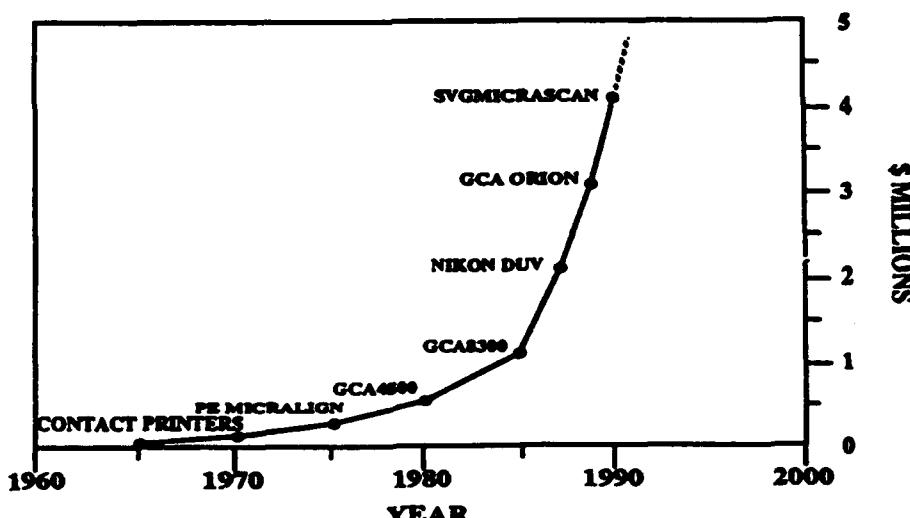


Figure G-2